FUEL CELL OPERATION ON ANAEROBIC DIGESTER GAS

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WE ARE RUNNING OUT OF ENVIRONMENT FASTER THAN WE ARE RUNNING OUT OF FOSSIL FUELS

ANAEROBIC DIGESTER GAS DEMONSTRATION
(Schedule of Project Events)

- Site is Yonkers, NY Wastewater Treatment Plant
  - — Conceptual design study defining issues associated with ADG as feedstock for fuel cells
    - Completed 1995
  - — Construction and testing of ADG pretreatment system
    - Completed 1998
  - — Two year field test of fuel cell energy recovery system
    - Completion scheduled for July 2001

METHANE GAS EMISSIONS

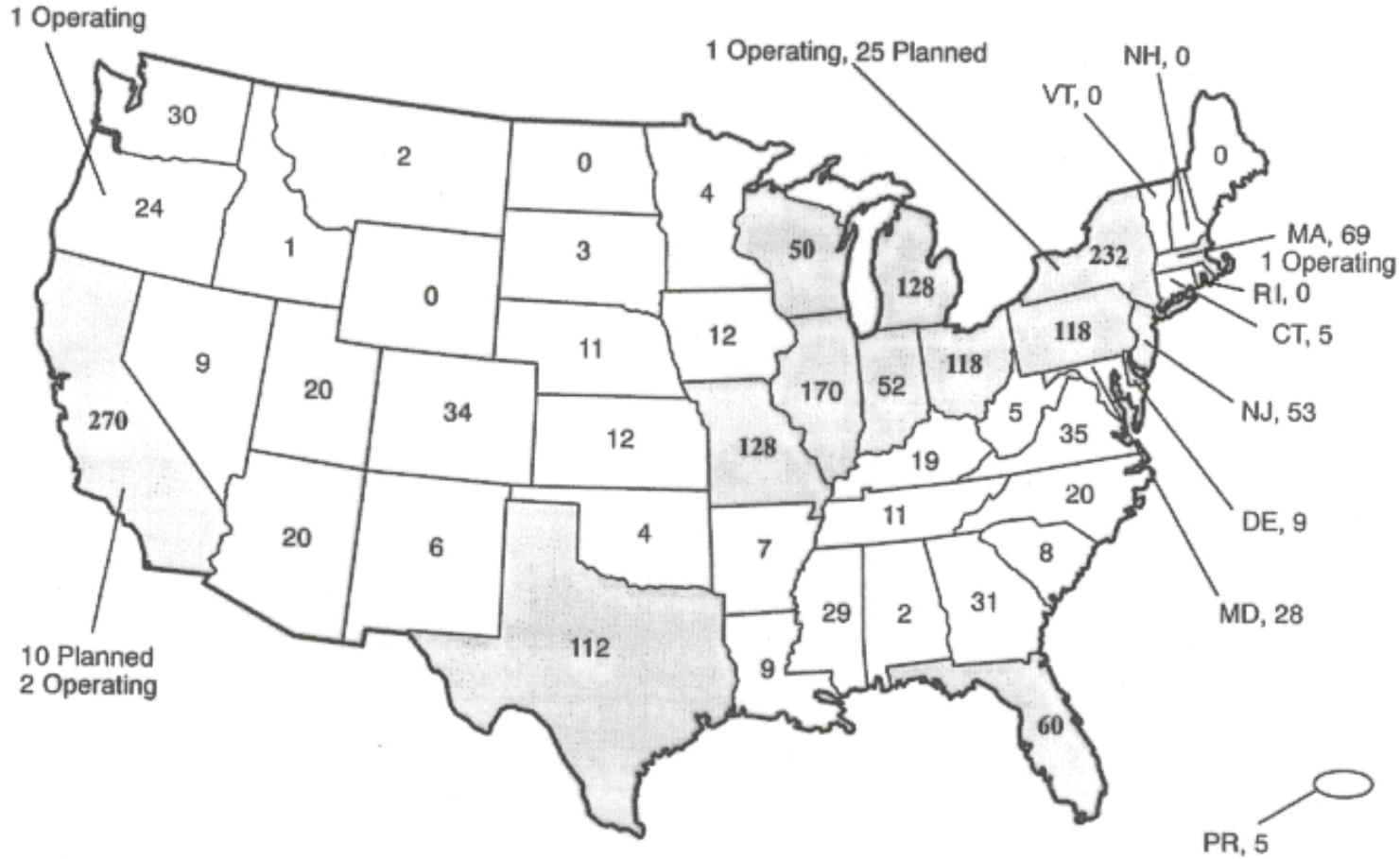
- Methane is a greenhouse gas, 20 times more potent than carbon dioxide
- Atmospheric concentration of methane has risen subnstantially during the the past few hundred years
- Total worldwide emissions are running about 500 Tg annually
- Methane buildup is estimated to contribute about 20% of the radiative forcing increase due to the buildup of all greenhouse gases
- Methane sources:
  - landfills
  - gas pipeline leaks
  - coal mines
  - rice cultivation
  - livestock operation
  - anaerobic digesters

POTENTIAL MARKET

Source	GLOBAL Methane (Tg/Yr)	GLOBAL Potential Electric Power (MW)	U.S. Methane (Tg/Yr)	U.S. Potential Electric Power (MW)
Landfills	35	11,000	9	2,700
Digesters				
***Water Treatment**	35	13,000	5	1,800
***Animal Waste**	15	5,300	3	1,000
Coal Mines	35	13,000	4	1,400

Conclusion: Large potential market for innovative technology with higher energy efficiency and minimal by-product emissions

LOCATION AND QUANTITY OF POTENTIAL ANAEROBIC DIGESTER GAS PC25 FUEL CELLS



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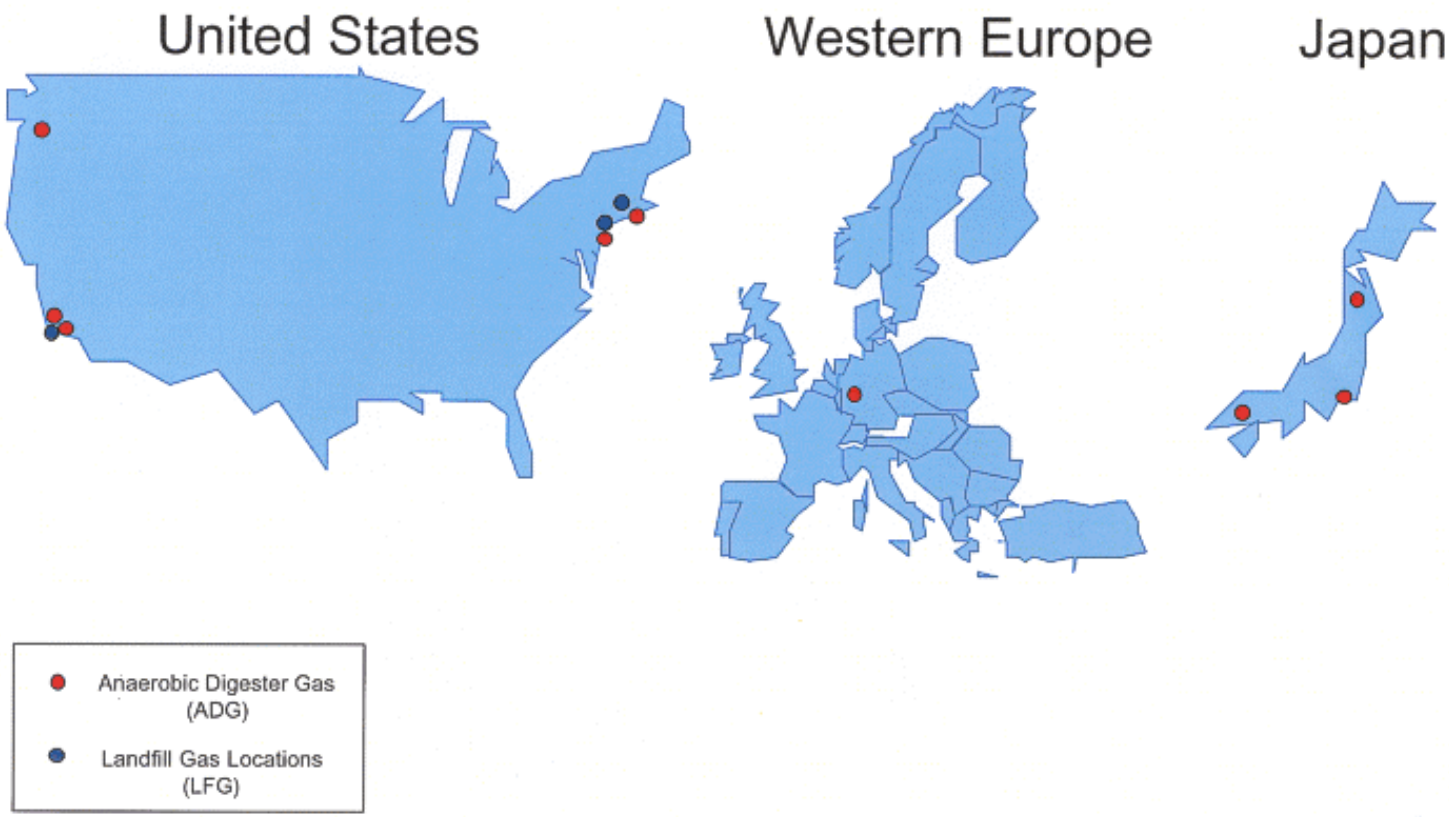
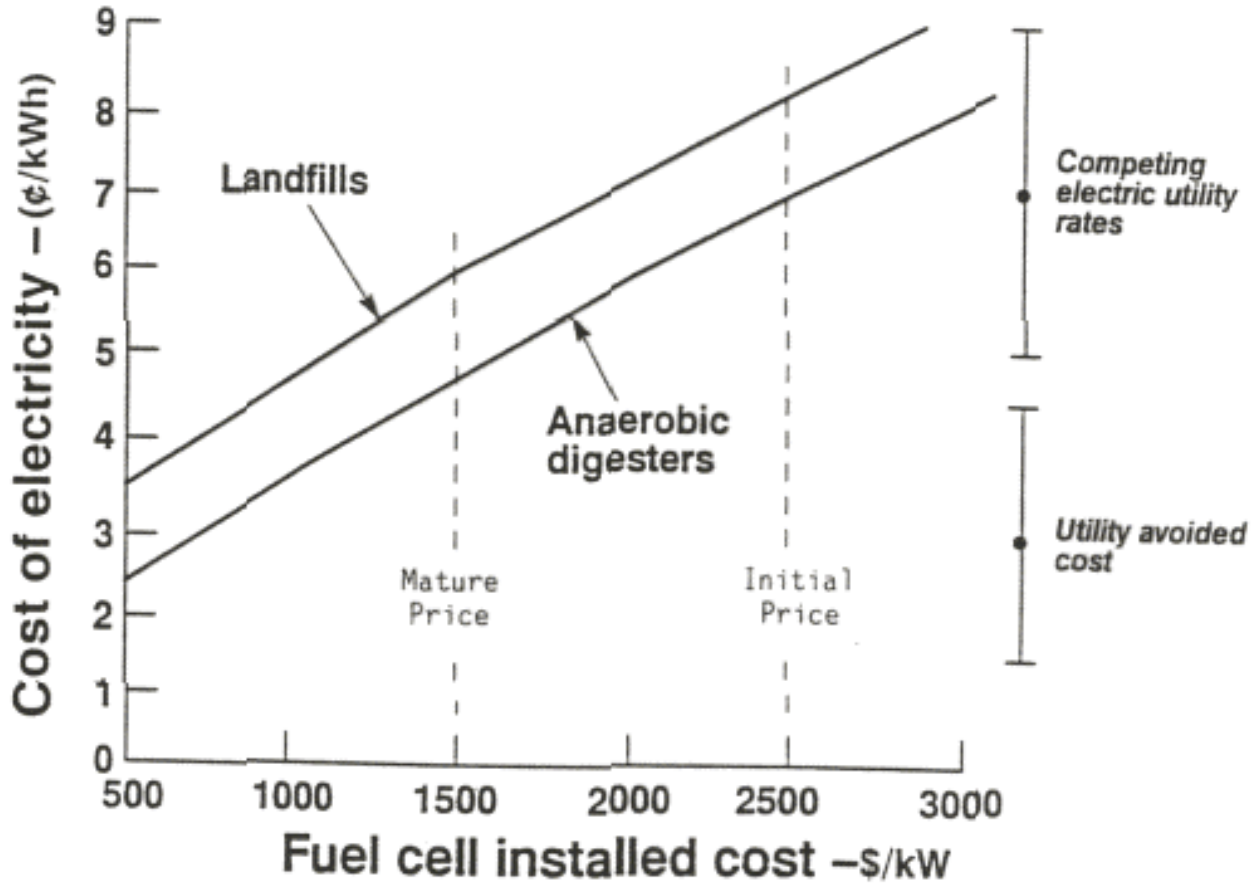
PC25 FUEL CELLS AT BIOMASS FACILITIES

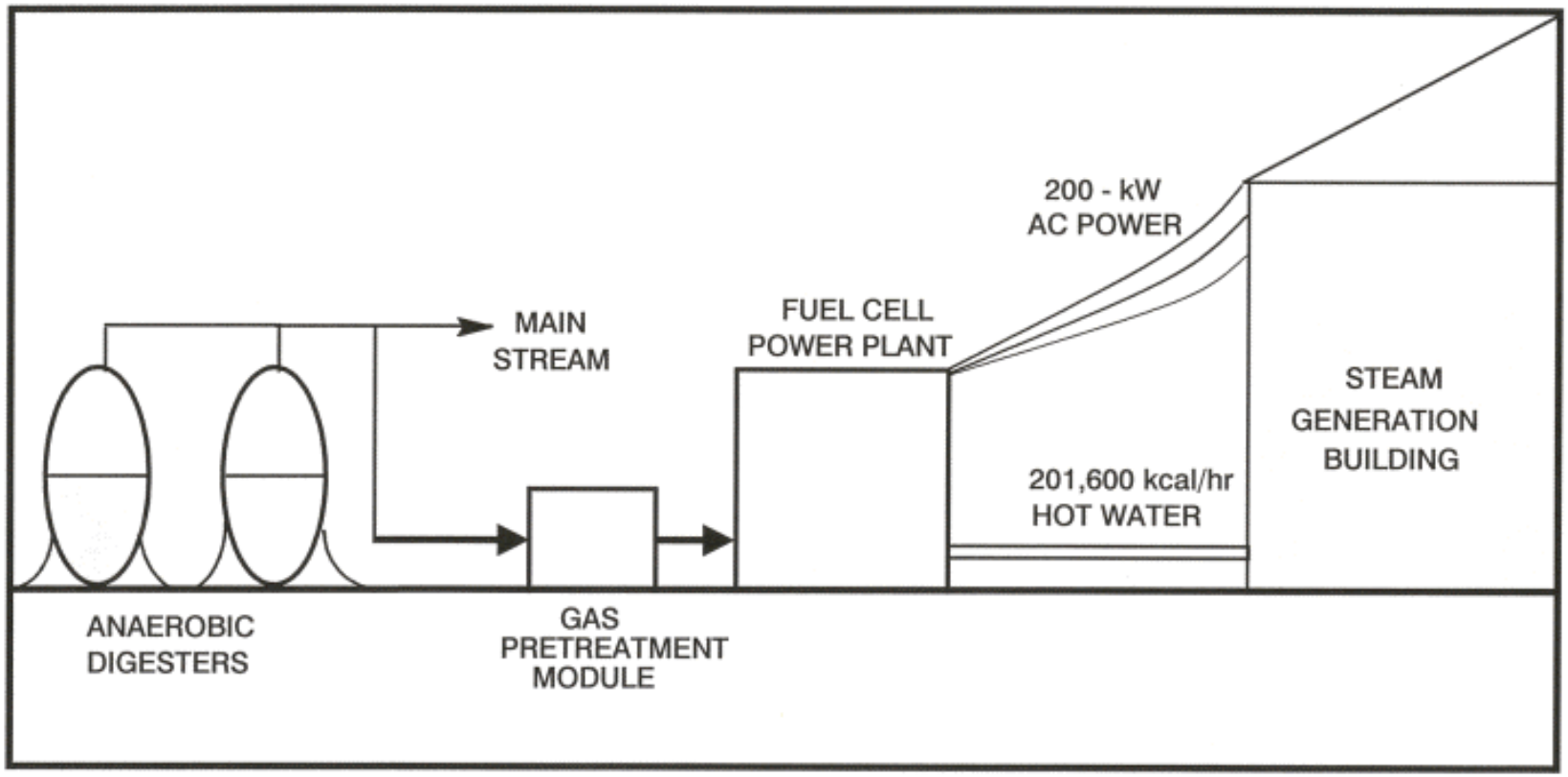


EMISSION REDUCTION

- 200 kW fuel cell operating on anaerobic digester gas
- North Atlantic Plant
- Emission reduction results from:
  - Displaced electricity
  - Flare elimination
- Pounds per year
  - 4,100 NO_x
  - 3,500 SO_x
  - 4,100 CO
  - 2,700,000 CO_2
  - 684,000 CH_4

WASTE METHANE/FUEL CELL COST OF ELECTRICITY





Fuel Cell / Digester Energy Recovery Concept

WASTE WATER TREATMENT

1045-7

Yonkers, NY

GAS CLEAN-UP ISSUES

- **Constituents that poison fuel cell catalyst**
  - **Sulfur**
  - **Halides**

- **Variability of gas composition**

- **Fuel cell has some built-in protection; supplemental clean-up required for waste methane sources**

PC25 MODIFICATIONS REQUIRED FOR ADG

- Larger fuel injector
  - Higher volumetric flow rate
- Larger piping
- Internal halide scrubber
- Software modifications
- External sulfur scrubber

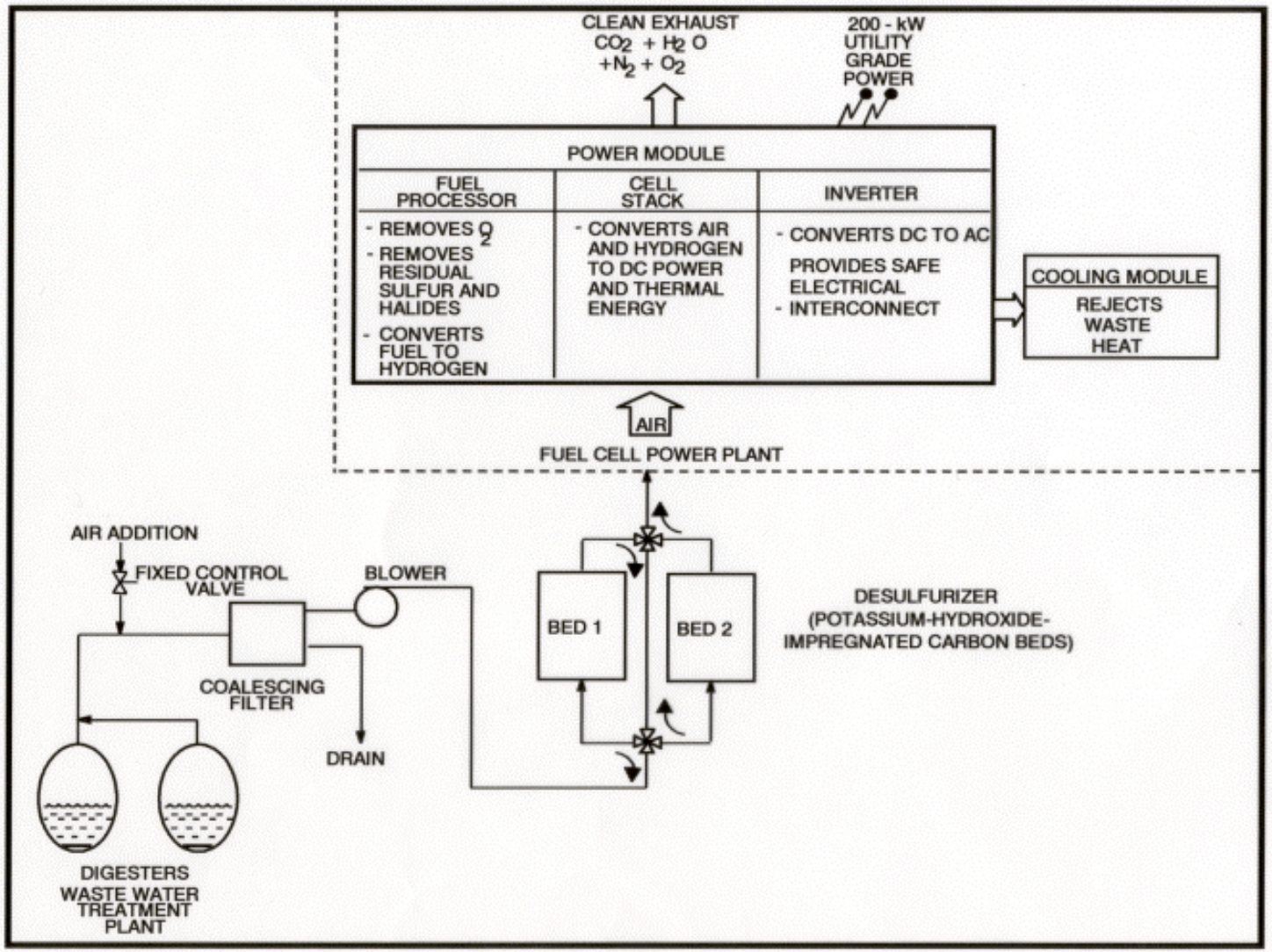


Figure 3. Process Schematic of Commercial ADG Pretreatment System

FUEL CELL POLISHER BEDS

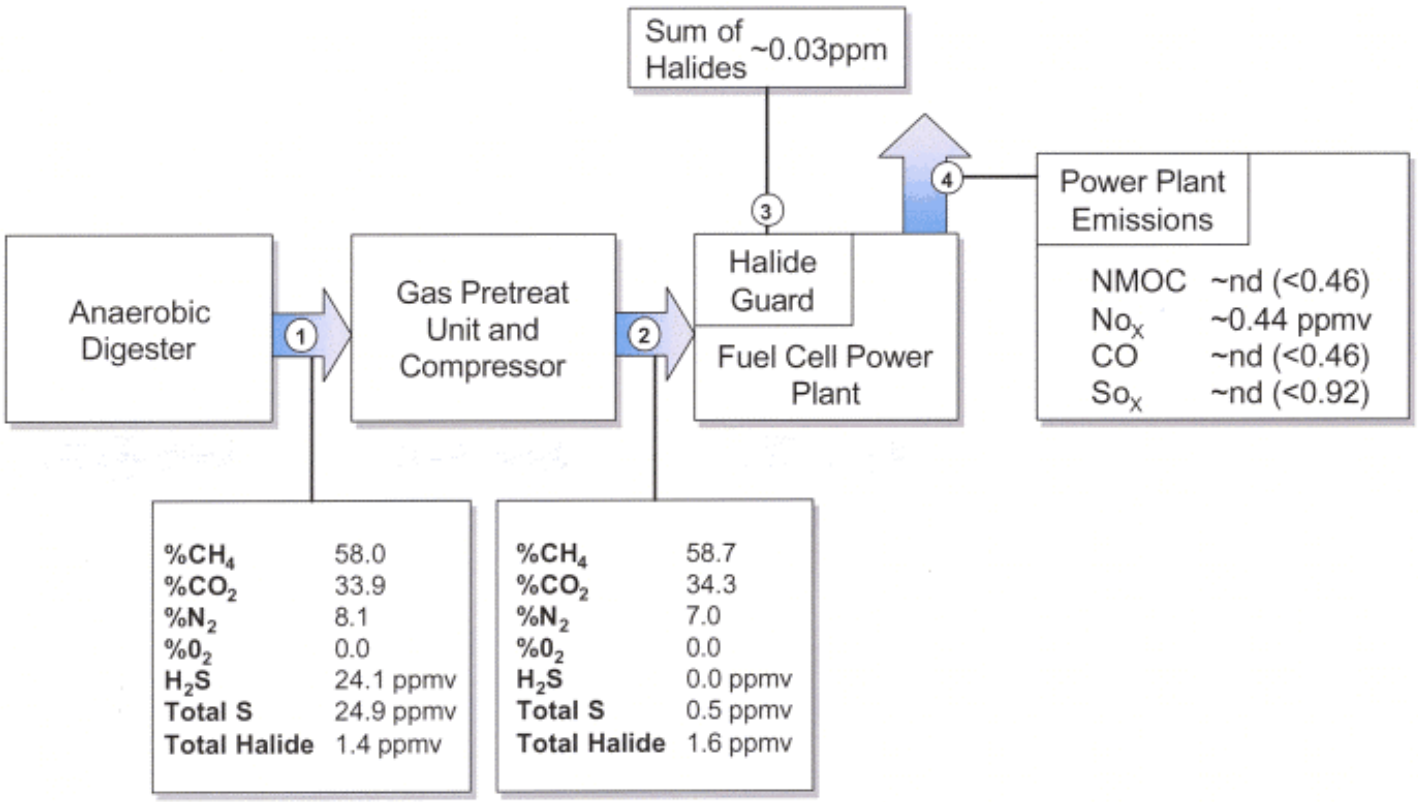
- **Zinc Oxide Catalyst**
  - **Reacts with sulphur compounds to remove sulphur**
  - **Catalyst converted to zinc sulphide**
- **Activated Alumina Impregnated with Potassium Permanganate**
  - **Potassium permanganate reacts to oxidize any remaining halogenated hydrocarbons**

TEST RESULTS

PERFORMANCE OF ADG SULFUR REMOVAL SYSTEM

SUMMARY OF ANAEROBIC DIGESTER GAS

Composition and contaminants, plus fuel cell emissions



YONKERS ADG FUEL CELL

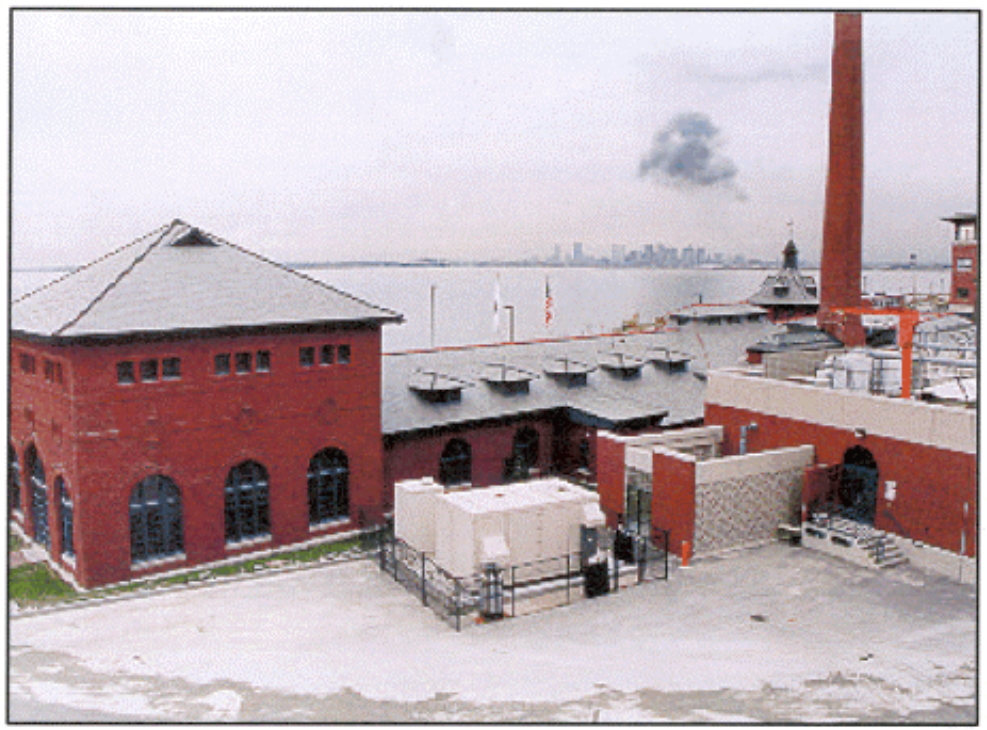
- Unit in operation ~ 3 years
- Successful operation
- Operation provided valuable “lessons learned”
  - Implemented in future power plants/Installations

"SPIN OFF" ANAEROBIC DIGESTER FUEL CELL POWER PLANTS FROM YONKERS DEMONSTRATION PROJECT

- **DEER ISLAND, MA (BOSTON HARBOR)**
- **PORTLAND, OR**
- **LAS VIRGENES MUNCIPAL WATER DISTRICT IN CALABASAS, CA (2 FUEL CELLS)**
- **COLOGNE, GERMANY**

USE OF ANAEROBIC DIGESTER GAS

Waste water treatment plant, Boston, Massachusetts



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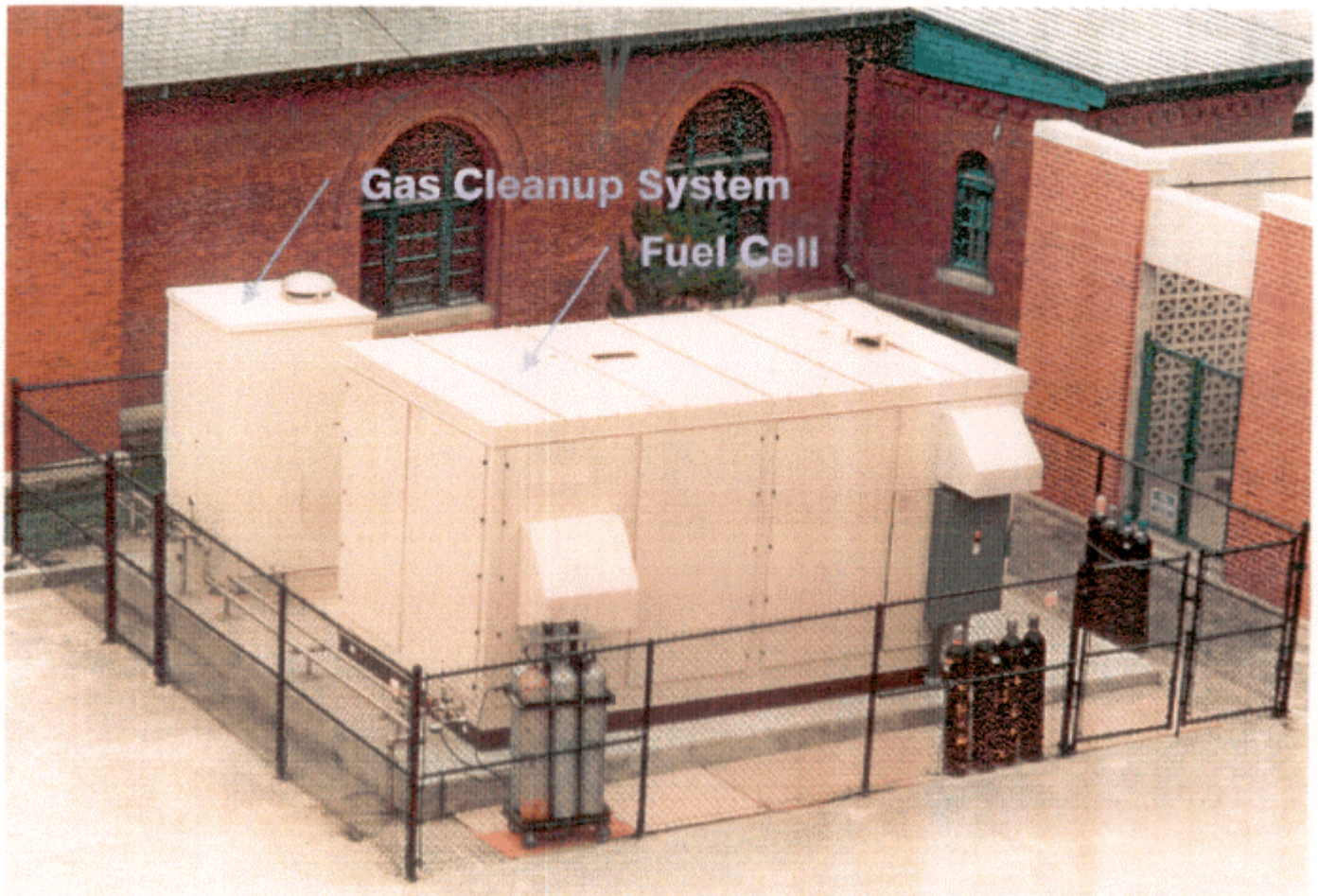

Anaerobic Digester Gas - PC25 Installation

CONCLUSIONS

- Digester gas market is viable today
  - Several commercial spinoffs
- Fuel cells are capable of being sited in NO_x and CO nonattainment areas
- No major technical hurdles
  - Commercial fuel cell technology available
  - Gas cleanup system works